The History of Galaxy Formation in Groups: An Observational Perspective

Christopher J. Conselice

School of Physics and Astronomy, University of Nottingham, UK

Summary. We present a pedagogical review on the formation and evolution of galaxies in groups, utilizing observational information from the Local Group to galaxies at $z \sim 6$. The majority of galaxies in the nearby universe are found in groups, and galaxies at all redshifts up to $z \sim 6$ tend to cluster on the scale of nearby groups (~ 1 Mpc). This suggests that the group environment may play a role in the formation of most galaxies. The Local Group, and other nearby groups, display a diversity in star formation and morphological properties that puts limits on how, and when, galaxies in groups formed. Effects that depend on an intragroup medium, such as ram-pressure and strangulation, are likely not major mechanisms driving group galaxy evolution. Simple dynamical friction arguments however show that galaxy mergers should be common, and a dominant process for driving evolution. While mergers between L_* galaxies are observed to be rare at $z < 1$, they are much more common at earlier times. This is due to the increased density of the universe, and to the fact that high mass galaxies are highly clustered on the scale of groups. We furthermore discus why the *local* number density environment of galaxies strongly correlates with galaxy properties, and why the group environment may be the preferred method for establishing the relationship between properties of galaxies and their local density.

1 Introduction

Astronomers have known since the time of Messier and the Herschels that the faint nebula, or what we today call galaxies, cluster together. This was before we knew anything else about these systems, including their distances. Galaxy clustering remains one of the cornerstones of cosmology and galaxy formation, and most galaxies are clustered in some form. This is one of the major successes of the Cold Dark Matter model of structure formation, and simulations show that the bulk of large-scale structure is composed of individual groups of galaxies [37]. This is found to be the case observationally [24],

and it appears that up to half of all nearby galaxies are in groups or clusters
[26].

The fact that a significant fraction of all galaxies are found in groups is
likely an important aspect for understanding galaxy formation and evolution.
We know that the local environment[1] of a galaxy correlates with most of its
properties. The most famous example of this is the morphology-density rela-
tion [23], where galaxies with early-type morphologies are more likely found
in denser areas, while spirals are more likely found in lower density environ-
ments. Galaxies in low local density regions also have a higher star formation
rate than those in areas with a higher local galaxy density [40,30]. Whether
the relationship between local density and the properties of galaxies is intrin-
sic, or is a result of physical processes that occur in dense regions after initial
galaxy formation is still an unresolved issue.

Galaxy evolutionary effects were also first noticed in the densest areas of
the universe - namely galaxy clusters. A high fraction of blue galaxies were
found in galaxy clusters at $z \sim 0.5$ compared to local systems [4]. These
star forming, or post-star forming galaxies, possibly provide evidence that
denser environments induce relatively recent evolution in galaxies. In fact, it
is largely unarguable that dense environments such as groups[2] and clusters
induce *some* evolution. When these effects occur, and to what degree they
alter the evolution of galaxies, is still open for debate.

In this review, we address some of these issues by focusing on the most
common environment of galaxies - the galaxy group - and how the cumulative
effects of a dense galaxy environment drives the evolution and formation of its
members. There are several reasons why the group environment is perhaps the
most important for understanding how galaxy formation and evolution occurs.
The main reason is due to the fact that most nearby galaxies are in group
environments, which we now know extends up to $z \sim 1.4$ [27]. Furthermore,
many of the physical processes associated with galaxy formation, e.g., galaxy
mergers, can *only* occur in group-like environments. Therefore groups appear
to be a gateway environment producing galaxies with drastically different
morphological and star forming properties from previous field galaxies.

The outline of this review is as follows: we first describe the final (thus
far) evolution of groups of galaxies and their properties by examining nearby

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[1]We often refer to local and global environments in this paper. The local en-
vironment is the density defined by the volume enclosing a galaxy and its nearest
bright neighbors. The global environment refers to the type of environment a galaxy
lives, whether it be a cluster, a group, or the field, without regards to whether the
galaxy is in the core or outer part of a cluster or group. The local environment can
be quantitatively measured through a nearest N neighbor approach detailed in e.g.,
[23,50], or through a friends-of-friend algorithm.

[2]We define a group as a gravitationally bound system of galaxies with less than
fifty members all within 1-2 Mpc, and with only a few bright $> L_*$ members. Typ-
ically, these systems have masses $\sim 10^{13} - 10^{14}$ $M_\odot$, and velocity dispersions of
150-500 km s^{-1}.

groups. We then extended these results to higher redshifts and examine processes, such as star formation and galaxy mergers, and how these might be driven by the group environment. Finally, we draw some conclusions regarding how the group environment might be influencing the evolution of most galaxies. The cosmology $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_\lambda = 0.7$, and $\Omega_m = 0.3$ is used throughout.

2 Groups in the Nearby Universe

2.1 The Local Group

The nearby universe provides a number of important clues for understanding how galaxies in groups evolved. The best studied example is of course our own Local Group, with its 35+ members, each of which has undergone a distinct formation history (see [31] and the Grebel review in these proceedings). The most effective way to determine when stars in Local Group galaxies formed is to study the resolved stellar populations within these systems. The derived star formation history of the Local Group is clearly very extended and variable, even for the most basic dwarf spheroidals. The star formation in these simple and morphologically indistinct galaxies occurred from roughly the time of reionization until a few Gyr ago [32]. Dwarf irregulars, and the spirals in the Local Group, including our own Milky Way, are by definition still undergoing star formation, but they also have old stars produced likely before reionization.

There are a few more interesting facts about the Local Group worth mentioning in regards to the history of galaxy evolution. While the Local Group contains four massive members (M31, the Milky Way, M33 and the LMC), it is dominated by lower mass dwarf galaxies. These dwarf galaxies tend to cluster around the two massive members, M31 and the Milky Way. There is also a strong environmental effect occurring within the Local Group dwarf population. The evolved dwarf spheroidal galaxies are located nearest the two giant spirals, while the star forming dwarf irregulars are located away from the giants. This is one example of how the *local* environment of a galaxy correlates with its properties. For more extensive reviews of the star formation history and properties of Local Group galaxies see [31,53].

2.2 Nearby Groups and the Morphology-Density Relation

Nearby groups, such as the Sculptor and M66 groups (Figure 1), contain a similar range of morphological and ongoing star formation properties as the Local Group. Because of their distances, it is difficult to reconstruct detailed star formation histories in these nearby groups, but they likely have similar histories as the Local Group.
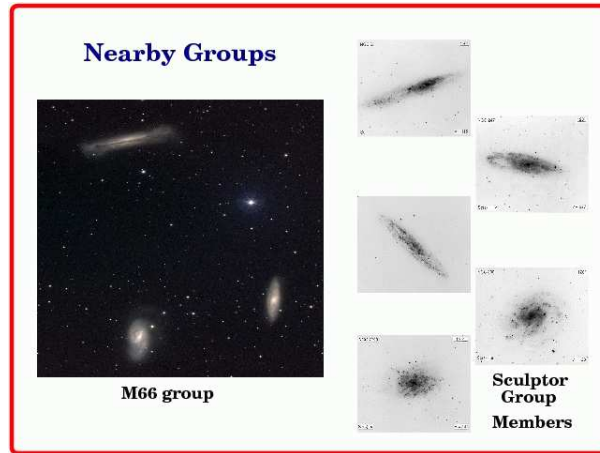
Fig. 1. Examples of galaxies in two of the nearest galaxy groups - the M66 group and the Sculptor group. The galaxies in these groups are similar to the Local Group, with many galaxies undergoing star formation, and in the M66 groups an ongoing interaction between members.

We can still however use other tools, such as morphologies and ongoing star formation in nearby group members, to understand how these systems are evolving. Star formation is still occurring in both large and small galaxies in group environments. Unless these groups recently formed, this implies that environmental effects that can reduce star formation, such as ram-pressure stripping [44] or the gradual depletion of hot halo gas around galaxies (so-called strangulation or starvation) [38], are not occurring - or at the very least they are not dominating effects. However, we can see environmental effects inducing evolution in the form of induced star formation, and morphological distortions due to galaxy-galaxy interactions, such as between M65 and M66, in the M66 group (Figure 1).

The morphology-density relation for nearby and distant groups and clusters reveals that galaxy formation is sensitive to local environment. This correlation is such that the higher the local projected galaxy surface density, the less likely a galaxy in that area will be a spiral, or undergoing active star formation [49]. However, [55] showed that the morphological-density relation does not hold in a global sense. Zabludoff & Mulchaey [55] found that groups of galaxies can have total early-type fractions as low as in the field, or as high as in clusters (fraction ~ 0.6), which is independent of the global environment. The local environmental density in which group early-type galaxies are found is as high as the densest environments in clusters of galaxies. The passive or early type galaxies in groups are also found in the centers of groups, where the local galaxy density is highest.

The star formation rate of a galaxy also does not correlate strongly, if at all, with its global environmental density as measured by velocity dispersions

[3]. It is not the global environment, such as living in a massive cluster, but the local environment which correlates with galaxy properties. Likewise, gravitational interactions between nearby galaxies only alter morphology, and induce star formation, when they are separated by less than a galaxy diameter [34]. Galaxy formation is therefore a local process.

Another nearby galaxy group type that deserve detailed discussion are the so-called compact groups. The compact groups, such as Seyfert's Sextent and Stephen's Quintet, are examples of galaxy groups where the members are within a galaxy diameter, and are likely to merge within about a Gyr. While there is some controversy over the existence of compact groups - some have argued they are chance alignments - the fact that there is a hot intragroup medium associated with these galaxies provides strong evidence that they are bound objects.

An indication that compact groups may be the progenitors of mergers between galaxies are the fossil groups [48], ghost groups, and the AWM groups [1]. These objects are all systems with massive and luminous X-ray emission, but only contain one bright central galaxy. There are some differences, such as the AWM group's central galaxy having a cD like structure. However, what is clear about these 'groups' is that although they consist of only one bright galaxy, they have X-ray profiles and dark matter halos that closely resemble groups. This suggests that these systems are recent merger remnants or the final stages of a galaxy group whose members merged together.

2.3 Galaxy Groups up to $z \sim 1.4$

Beyond about $z \sim 0.3$ there have been few searches and systematic studies of groups of galaxies, although this is rapidly changing. The first evidence that galaxy groups at high redshift evolve was provided by Allington-Smith et al. [1] who discovered populations of galaxies surrounding radio sources at $z \sim 0.5$. They furthermore found that at the same local environmental density, there is a larger amount of star formation in galaxies in groups at $z \sim 0.3$ compared to lower redshift clusters. This is similar to the Butcher-Oemler effect found in clusters, and possibly arises from the same mechanism(s).

The first proper redshift surveys at $z > 0.3$ found significant peaks in galaxy redshift distributions [10,7], suggesting that real over-densities of galaxies exist beyond the local universe. The CNOC2 survey pioneered efforts to characterize the galaxy population in groups at these redshifts [54], which has only recently been superseded by the DEEP2 and VVDS redshift surveys [21,27,36].

The CNOC2 groups at redshift $z \sim 0.5$ display remarkably similar scaling properties as field galaxies at similar redshifts, and in comparison to $z \sim 0$ groups. [54] found a large blue galaxy fraction in both the field and in groups up to $z \sim 0.5$, with a similar rate of decrease in both environments at lower redshifts. However, there are more passive galaxies in group environments at

all redshifts, suggesting that the correlation of environment in groups with the properties of its member galaxies existed at least 5-6 Gyr ago.
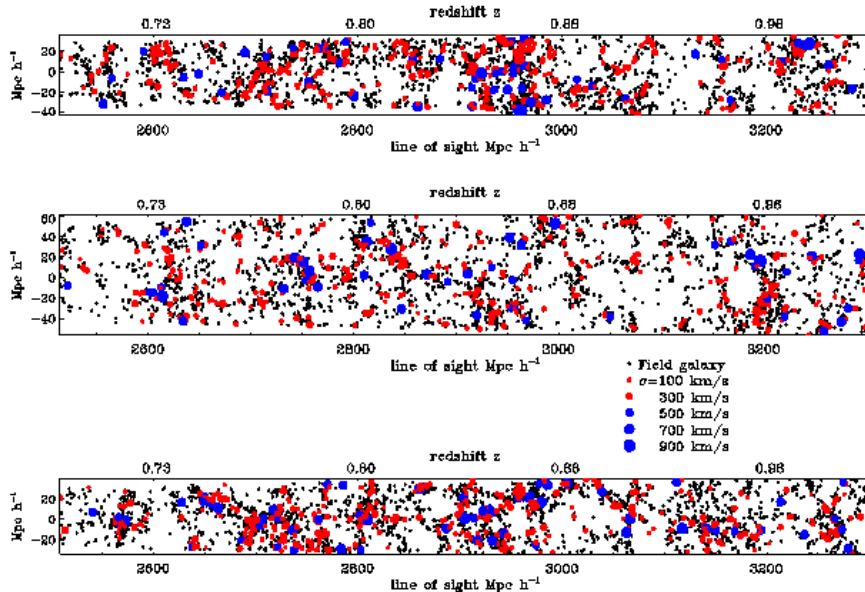

Fig. 2. The distribution of groups in redshift space as seen in the DEEP2 redshift survey [27]. The larger symbols represent groups/clusters with larger velocity dispersions, with groups at dispersions of $z < 300$ km s^{-1} labelled as the smaller (and red) points. (Courtesy of Brian Gerke)

Redshift surveys with a high velocity resolution, such as DEEP2 and the VVDS, are allowing us to trace how galaxies cluster out to $z \sim 1$. One result of these studies is that galaxies, particularly bright galaxies, cluster strongly out to $z \sim 1.4$ [9]. Using various cluster/group finding techniques such as the Voronoi-Delaunay method, individual groups of galaxies can be identified and studied out to these redshifts [27] (Figure 2).

Once we have found these groups we can then try to determine how environment drives evolution up to $z \sim 1.4$. Bundy et al. [5] have approached this problem recently through using stellar mass functions at different environmental densities and redshifts up to $z \sim 1.4$ (Figure 3). By fitting the spectral energy distributions of galaxies in the BRIJK bands to different star formation histories, [5] calculated the most likely stellar mass to light (M/L) ratio for all galaxies within the DEEP2 spectroscopic survey. Through the use of the observed K-band flux for these galaxies, and the derived stellar M/L ratio, a stellar mass is calculated. The mass function for galaxies in high density
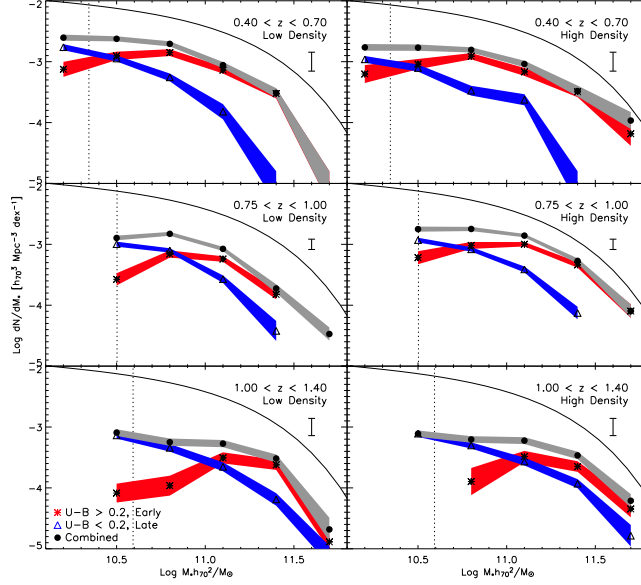
Fig. 3. The stellar mass function from [5] plotted as a function of density and redshift (time). The mass functions are furthermore divided into red and blue galaxies. The transition between blue and red galaxy dominance, i.e., when $M_{blue} > M_{red}$ does not change with a broad environmental density cut.

environments compared to those in low density environments, as measured through a 3rd nearest neighbor statistic in shown in Figure 3.

Figure 3 shows that mass functions in low and high density environments are similar up to $z \sim 1.4$. This implies that environment in a very broad sense is not a critical component for the formation of galaxies - that is, a galaxy or a potential proto-galaxy's formation by $z \sim 1.4$ does not strongly depend upon whether it is in a dense region or a lower density region. There are however some differences between mass functions in low and high density environments, as galaxies at the extreme ends of the environmental density distribution show significant differences. There are more massive galaxies in higher density environments (cf. [36]), but the overall mass function shape, and the characteristic masses of star formation galaxies (i.e., the downsizing) are similar. This furthermore implies that environmental processes that could trigger, or halt, star formation in groups are not major effects, at least since $z \sim 1.4$. This is partially simply another way of saying that most galaxy stellar mass is formed by $z \sim 1.4$. However, there is some star formation evolution in both field and group/cluster galaxies as observed through direct measures [41], as well as increased blue fractions (i.e., Butcher-Oemler). However, this additional star formation does not induce large amounts of new star formation

in massive galaxies, and most star formation is occurring in low-mass galaxies at $z < 1.4$ in both low and high density environments.

2.4 Young Galaxies at $z > 2$

Large samples of galaxy groups at redshifts larger than $z \sim 1.4$ do not yet exist. What we do have is considerable evidence that $z > 2$ galaxies appear to be clustered, and are in environments that are either group-like, or forming into groups. In fact, there is considerable evidence that higher redshift galaxies are strongly clustered, with the most massive galaxies (examples shown in Figure 4) the most clustered [28,20,39].
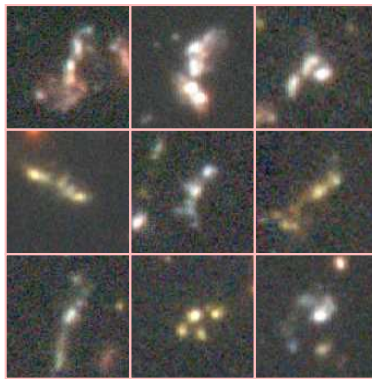

Fig. 4. Examples of high redshift bright galaxies as seen in the Hubble Deep Field. These types of galaxies are the most clustered and often shown direct signs through color gradients, and structures, for a recent merger origin.

Examples of this clustering can be seen all the way back to where the earliest galaxies are seen. For example, deep Hubble Space Telescope (HST) imaging of bright $z \sim 6$ QSOs show an excess of red $(i - z)$ galaxies surrounding these systems [56]. If these QSOs are the sites of massive galaxy progenitors, then it seems likely that they and their companion galaxies will evolve to become a virialized system - perhaps a group or a cluster. Making the connection between these 'groupings', and modern clusters/groups is not as difficult as it might seem. The large statistical excess of objects with red $(i - z)$ colors strongly suggests that these objects are spatially associated with each other. They are furthermore found within a projected radius of a Mpc or so - which is the typical size of a group or cluster core.

Although we can detect galaxy clustering through various techniques out to $z \sim 6$, often we know very little about the formation modes of these galaxies, except that they are undergoing star formation. Internal galaxy properties as observed with HST, and integral field units, can only be studied in large

numbers at $z < 3$. There is now abundant information about these young galaxies which suggests that their clustering, and perhaps grouping, is driving their formation and evolution.

Galaxies at $z > 1.4$ are generally found to cluster quite strongly on small (~ 1 Mpc) scales. A recent example of this comes from the Great Observatories Origins Deep Survey (GOODS; 29). Due to the high quality and depth of the GOODS Hubble Space Telescope imaging it is possible to use the Lyman dropout technique to find galaxies undergoing unobscured star formation at $z \sim 3$ and $z \sim 4$. The correlation function for these systems has an excess at small scales over a power-law. This excess can be explained by a two component model for galaxy clustering, such that a large scales galaxies are in single halos, where as at small scales two galaxies per halo are needed to explain the excess [39]. There is also a luminosity dependence to this clustering, such that the most luminous galaxies are the most clustered [28,39]. We will address in the later part of this review how this clustering might be driving the formation of galaxies found in early groups.

3 Physical Processes in Groups

3.1 Possible Formation Mechanisms

Galaxy evolution occurs via both internal and external drivers. The environments of galaxies should have some effect on how galaxies evolve. For example, if galaxies are surrounded by other galaxies then gravitational interactions and mergers can induce the formation of new stars, remove stars/gas from galaxies due to tides, increase the masses of galaxies through accretion of satellites, decrease the number of galaxies from mergers, and change the morphological types of galaxies. Furthermore, if there exists an intragroup or intracluster medium then gas can be removed from member galaxies through processes such as ram-pressure stripping and strangulation [38]. All of these processes are going on, but their strength and time-scales are still very much debated. We discuss each of these processes below, and why it appears that galaxy mergers are likely the dominate method by which galaxies in groups are evolving in the early universe ($z > 1.5$).

The efficiency of these various processes can be characterized by the velocity dispersion σ of an environment. Ram pressure stripping has an induced pressure force $\sim \rho\sigma^2$, where ρ is the density of the intergroup medium. As the velocity dispersion of groups are typically $\sim 250-400$ km s^{-1}, the efficiency of this process in groups is likely not great, and its influence in clusters of galaxies where both ρ and σ are both high is also not clear. Likewise high speed galaxy interactions, such as galaxy harassment [46], are unlikely to produce significant effects in groups due to the low relative velocities of member galaxies. This type of process is most efficient in rich clusters of galaxies where the velocity dispersion is high, and galaxies are rapidly interacting with cluster

members [45]. Interactions between a group galaxy and the potential of its group [6] are also unlikely to be very effective given the low masses of groups.

Strangulation/starvation is the processes whereby hot gas is removed from a galaxy's halo after it enters a hot medium. This is proposed to halt the star formation in the accreted galaxy, as eventually no hot gas is left to cool and form new stars. It is however not a fast process, and has a time-scale of roughly a Gyr in clusters. It also requires a removal mechanism, which is usually an intracluster medium, that interacts and removes hot gas from orbiting galaxies. These mechanisms cannot be effective however as we see star formation occurring in groups. Unless these groups are young, the time-scale for truncation of star formation via ram-pressure and strangulation must be longer than a Hubble time. This leaves galaxy mergers and low velocity interactions, and non-gravitational processes, such as AGN feedback, as major effects that drive the evolution of group members.

3.2 Galaxy Mergers

Galaxy mergers should be common in groups of galaxies. This is due to the low velocity dispersion of galaxies in groups, and the close proximity of members. Various types of nearby groups, such as the compact groups and the fossil groups, are possibly the result of the merger process. A simple way to understand this is through dynamical friction effects which have a time-scale that varies roughly as as $\tau_{\mathrm{merge}} \sim \sigma^3$. Lower velocity dispersion groups therefore have a shorter time scale for mergers than galaxies in clusters. This is one reason why galaxy-galaxy mergers in the centers of massive clusters are rare. Simple calculations show that groups with velocity dispersions > 300 km s^{-1} will not have a significant number of mergers over a Hubble time. This is one reason why galaxy mergers, almost by definition, must occur in groups of galaxies.

Galaxy mergers and interactions are sometimes observed in nearby groups, which may be a common way to induce star formation in these systems. However, galaxy mergers in nearby groups, and in groups up to $z \sim 1$, are not expected to be common. Simulations and analytical calculations of the dynamical friction process show that galaxies in groups become more centrally concentrated by about a factor of two since $z \sim 1$ [8], but do not necessarily merge. The effect is strongest for groups with lower velocity dispersions, < 150 km s^{-1}. [8] argues that merging in groups at $z \sim 0.4$ should be low, about 2% per Gyr per group. Observations tend to agree that the merger fraction for massive galaxies is not high (but does increase) at redshifts $z \sim 0 - 1$ [13,42,43].

The merger rate for galaxies in groups should increase significantly at earlier times, that is at $z > 2$. The reason is simply because the universe was denser and galaxies were physically closer together, and should thus merge more often. A simple argument shows this to be the case. In a Λ-dominated universe, the mass density increases as the Hubble parameter squared, or H$^2 \sim$
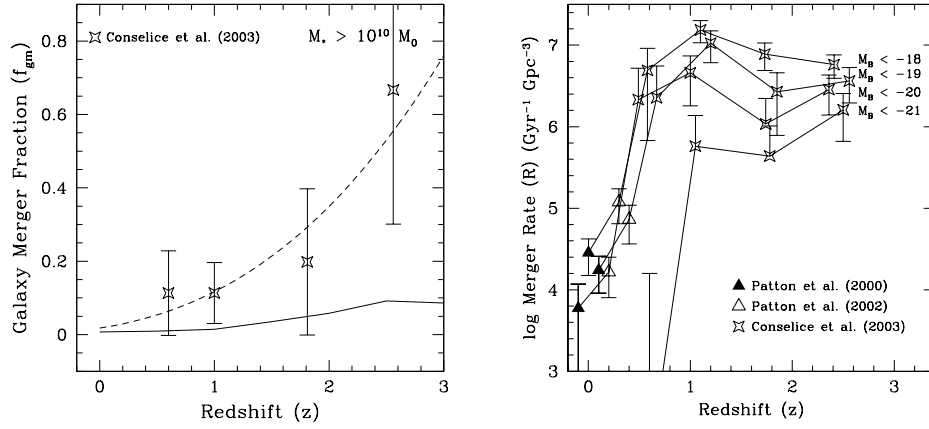
Fig. 5. Left panel: The galaxy merger fraction evolution for systems with $M_* > 10^{10}$ $M_\odot$ as a function of redshift [13]. Right panel: The galaxy merger rate in units of Gyr^{-1} and Gpc^{-3} as a function of redshift. The merger rate at $z > 1.5$ is very high for galaxies at all luminosities. The merger fraction for the most massive galaxies is also high - around 50% [19].

$(1+z)^3$, with a merger rate $\sim \sqrt{(H^2)} \sim (1+z)^{1.5}$. This merger rate explains why we see a mix of galaxy types in groups, such as early types and spirals with bulges. These spheroidal components were formed when systems underwent mergers early in the universe, with disk/bulge systems the spheroids who were able to re-acquire a disk via gas accretion from the intergalactic medium.

Finding mergers and calculating the merger rate at $z > 1$ has been carried out using deep Hubble Space Telescope imaging [13]. The merger fraction evolution out to $z \sim 3$ has been computed utilizing structural methods, such as the CAS system [11,15,16], and rest-frame optical observations of galaxies with NICMOS imaging of the Hubble Deep Field [22]. This imaging revealed that galaxy morphology changes gradually from normal ellipticals and spirals to peculiar galaxies at $z \sim 0$ to $z \sim 3$ [18]. In the nearby universe most of the bright $M_B < -20$ galaxies are normal Hubble types – spirals and ellipticals. However, when we view younger galaxies at higher redshifts we find that the fraction, and number densities, of peculiars rises at the expense of normal galaxies [47]. This morphology-redshift relation has been interpreted as an increase in the merger fraction with time [13].

The merger fraction varies with magnitude and stellar mass, such that the brightest and most massive galaxies have the highest merger fractions at $z \sim 2.5$. This merger fraction declines steeply with redshift approximately as a power-law, $f_m \sim (1+z)^{3-5}$ (Figure 5). The merger rate can be calculated using N-body models of the merger process to obtain the time-scale for mergers to

occur as seen through the CAS system [19]. Using models with various orbital properties and viewing angles, the time-scale for identifying mergers in the CAS method is roughly 0.38±0.1 Gyr for galaxies with stellar masses $> 10^{10}$ $M_{\odot}$. Knowing this time-scale allows us to calculate the merger rate evolution for galaxies as a function of time and stellar mass. The result of this is shown in Figure 5.

Integrating the merger rate with time lets us determine the number of major mergers a galaxy with a given initial stellar mass has undergone since $z \sim 3$. This simple calculation, explained in detail in Conselice (2006) [19], results in $4.4^{+1.6}_{-0.9}$ major mergers since $z \sim 3$ for galaxies with initial masses $> 10^{10}$ $M_{\odot}$. This allows galaxies with stellar masses of $\sim 10^{10}$ $M_{\odot}$, which tend to be among the most massive galaxies at $z > 2$, to grow by a factor of 10-15 to contain as much stellar mass as the most massive galaxies in the local universe. Most of this merger activity occurs at $z > 1.5$, with on average no mergers occurring at $z < 1$ for the most massive systems.

What does an increase in the merger rate with redshift have to do with galaxy evolution in groups? We unfortunately do not yet know how the merger rate varies with redshift *and* environment, but through a chain of observations, we can argue that these mergers are occurring in group-like environments. The argument is simple - the mergers we see occurring at $z > 2$ are in the most massive galaxies, which previously must of been bound pairs or groups. These massive galaxies are also clearly the most clustered, as shown by [28] and [39]. The scale of this excess clustering is small - about 1 Mpc - similar to the size of a group.

4 Discussion

4.1 Environmental Correlations

As we have already described in this review, there are several environmental correlations between the local density of a galaxy and that galaxy's properties. Perhaps one of the most interesting characteristics of these correlations is that there is little to no global environmental influence on the evolution of galaxies. This can be shown in a number of ways, including the fact that the star formation rate of galaxies, measured through Hα equivalent widths, correlates with the local projected surface density of galaxies. What is surprising is that this is independent of global environment, such that the correlation is nearly the same in both clusters with $500 < \sigma < 1000$ km s^{-1} and within groups with $\sigma < 500$ km s^{-1} [3].

What is the origin of local density sensitive properties of galaxies? This relates to the classic 'nature vs. nurture' debate about whether galaxy properties are imprinted early in their history, or whether they are transformed by their environment. We can argue now with some confidence that the observed correlation between galaxy properties and local density is likely a 'nature'

process at low redshift, but a minor one that largely involves halting star formation in accreted spirals. Except for low mass systems [45], it is unlikely that environment induces significant morphological effects outside of mergers. At higher redshifts where most star formation and morphological evolution occurs, the eventually properties of a galaxy are sealed by its local environment.

We can argue this through observational properties of galaxies and basic theory. First, areas of higher density are predicted to form earlier than those in lower density areas, as simple density arguments and simulations show [51]. This implies that the first galaxies should form in higher density areas. This however does not necessarily imply that galaxies in high density regions should be different (other than age) from galaxies in lower density areas. Observationally, we know that the most massive galaxies at $z > 2$ tend to have peculiar morphologies, and average stellar masses of $z \sim 10^{10}$ M$_\odot$ [18,47]. Elliptical and spiral morphologies were not in place until $z \sim 1 - 1.5$, and the morphology-density relation is already in place by then [49]. The seeds of the morphology-density relation therefore must have occurred even earlier when massive galaxies are already highly clustered.

Galaxies in higher density regions in the early universe are rapidly merging with each other. The progenitors of these galaxies are not spirals, but simply post-mergers, with multiple mergers occurring in a short time interval of a few Gyr [19], providing no time for the establishment of a stable morphology. Disk galaxies are likewise able to form after the merger epoch has ended. In this sense the morphology and stellar mass of a galaxy is set by the local density in which it forms. The global density is less important for driving galaxy evolution, as merging activity is the dominant process. By their nature, mergers are a local process driven by potentials dominated by a few massive systems, or what we call in the local universe galaxy groups.

The fact that the star forming properties of galaxies only depend upon local environment, and not global environment, is a strong indicator that whatever process is driving the decrease in star formation with local environment is not related to the total velocity dispersion (or density) of the system where a galaxy is located [35, 3], nor to the density of the intracluster or intragroup medium. The quenching of star formation in massive galaxies is however perhaps not driven entirely by environmental effects. The star formation properties of a galaxy appear to correlate with galaxy mass more strongly than with environmental density. The internal properties of galaxies, either through regulation with an active nucleus [33], or from the time-scale for the exhaustion of gas must be responsible for shutting down star formation. What is not yet clear is why massive galaxies do not reestablish a cold gas supply, nor have their hot gas cool and form stars. This is perhaps related to the galaxy downsizing whereby star formation is truncated in higher mass galaxies before lower mass systems at $z < 1$ [5].

4.2 Dwarfs and the Global Environment

One galaxy property that does not simply correlate with local environment is the faint end of the luminosity function, or the ratio of dwarf to giant galaxies. This correlation is such that in higher density global environments, the number of low mass galaxies per giant galaxy is much higher than in lower density environments [25]. This tells us first of all that galaxy clusters cannot form through the mergers of lower mass galaxy groups. This implies that in *global* high density environments there are processes that somehow produce low mass galaxies. There is no definitive agreement on how this occurs, with both a primordial origin suggested [52], as well as scenarios in which dwarfs are formed after clusters are in place [12,14]. For a more detailed discussion of this issue see [17].

5 Summary

Various observational techniques allow us to study the evolution of galaxies in groups, and in group-like environments up to $z \sim 6$. By studying galaxies in groups at various redshifts we can determine the modes by which most galaxies evolved. Four main features of galaxies in groups suggest how evolution has occurred in this most common environment.

I. The morphological and star forming properties of galaxies in low redshift galaxy groups reveal that multiple galaxy formation modes have occurred. This is due to the presence of star forming galaxies, such as spirals and irregulars, as well as evolved galaxies, namely ellipticals and dwarf ellipticals. There are also several examples of galaxies evolving in nearby groups through interactions/mergers.

II. Groups, in a traditional sense of having a measured velocity dispersion and found within a small volume, can be identified out to $z \sim 1.4$. Out to these redshifts we know that the group environment is very common with as much as 50% of all galaxies located in groups.

III. Galaxies in groups out to $z \sim 0.5$ evolve in a similar manner as the field, although groups tend to have a more evolved population at all redshifts thus far probed. This implies that the galaxy formation process, or at least residual star formation, is halted more quickly in groups than in the field. This may however be an effect of groups containing more massive galaxies, which end their star formation earlier than low mass systems. What triggers the star formation in galaxies in groups is still not resolved, and the cause may not differ from what is triggering star formation in field galaxies.

IV. At higher redshifts, there is evidence for groups in the form of strong galaxy clustering, and merging, which produces larger galaxies. The universe was denser at high redshift by a factor H^2, and thus galaxies were closer

together. The time-scale for these systems to merge is fairly quick, and this is likely the method whereby most early type galaxies and bulges were formed. This is also a natural method for putting the morphology-density relation into place. What remains a mystery is what causes the end to star formation in the most massive galaxies, and why no further star formation occurs.

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